FINAL REPORT: Quantification of Gaseous Emissions from California Broiler Production Houses

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Abstract

Methods and equipment were developed to analyze emissions from a broiler production house utilizing standard source test methods. A test stack was designed and fabricated to meet engineering testing criteria for fan exhaust air from a broiler production facility. Emissions of ammonia and organic gasses were measured periodically during the 55 day poultry production cycle including 45 days of production and 10 days between broods. Several methods were used for analysis of organic gasses and it was found that a gas chromatography/mass spectrometry analysis from samples collected in evacuated summa canisters was more useful than hydrocarbon methods for the low concentrations and complex gas mixtures encountered. An emissions factor of 0.0143 lb bird^{-1} raised for ammonia and 0.0061 lb bird^{-1} raised for total organic gasses is estimated. Several compounds (including acetone, dimethyl disulfide, ethanol, methanol, propane, and vinyl acetate) dominate the mass of organic gasses emitted from the house according to the mass spectrometer analysis. These may be from distinct sources within the house. The estimated emissions factor for reactive organic gasses (organic compounds with ozone forming reactivity) is 0.0037 lb bird^{-1} raised.

Introduction

California has significant particulate matter and ozone air quality problems. To help solve these problems, it is necessary to estimate the emissions of air pollutants for all major industries. In the past, the livestock industry was not considered an important emissions source from an air quality perspective. To meet regulatory and public policy needs, a better understanding of livestock emissions is needed. The objective of this study was to estimate the gaseous emissions from a broiler production facility during the broiler growth cycle and develop emissions factors per bird of production.

Airborne emissions from broiler production facilities have been quantified in other studies. Ammonia emissions have received the greatest amount of attention and several researchers have quantified emissions from broiler production houses. Casey et al. (2003) reported ammonia emissions from eight broiler houses in Kentucky during the winter months ranging from 0.10 – 0.98 g day^{-1} $bird^{-1}$ for birds from 11 to 56 days old. They found that emission rate increased with bird age but appeared to be a relatively constant function of bird weight with an average emissions rate of 163±56 g day^{-1} 500 kg^{-1} live weight. The high degree of variability was attributed to different litter handling and other management practices. Lacey et al. (2003) reported ammonia emissions ranging from 0.05 – 1.90 g day^{-1} $bird^{-1}$ with an average of 0.63 g day^{-1} $bird^{-1}$ for broilers raised in central Texas over a 49 day growth cycle. The average cycle emissions were estimated as 31 g $bird^{-1}$ raised. This study found that ammonia emissions were approximately linear with live weight of birds with an average emissions rate of about 300 g day^{-1} 500 kg^{-1} live weight. This was found to be higher than reported emissions from several European studies (Wathes et al., 1997; Groot Koerkamp et al., 1998; Demmers et al., 1999; Hyde et al., 2003) but in the same order of magnitude. Climate, litter management, feed, bird weight, stocking density and measurement methodology all may contribute to differences.

Quantification of volatile organic compounds from broiler houses has received minimal attention from the research community. It has been reported that animals and their waste can emit over 130 organic compounds (O'Niell and Phillips, 1992) although an abbreviated number of these may only be important when considering mass emissions (Hobbs, 2001). Gas chromatography/ mass spectrometry (GCMS) has been used to identify odor compounds related to malodor in poultry manure (Yasuhara, 1987). These malodor compounds have very low detectable threshold for human beings with some even below the detectable limits of test equipment. A recent odor study (Chang and Chen, 2003) collected samples on sorbent tubes and analyzed them using GCMS to identify compounds from broilers produced in laboratory chambers. They tentatively identified compounds with the greatest response to include ethanol, dimethyl disulfide, 2-propanone, 2-propanal, 2-butanone, and benzene with a total of 24 distinct GCMS peaks. In another study (Hobbs et al., 1995) the headspace concentrations of compounds above manure was measured. They found that dimethyl sulfides (primarily dimethyl disulfide) were highest in poultry manure, but found relatively little of the C2 to C9 organic acids found in pig and cattle manure.

Directly emitted particulate matter emissions are also a concern from poultry production houses. Particulate matter primarily originates from litter, feed, skin and feathers that can become airborne induced by animal and air movement within the poultry facility (Grubb et al. 1965). Total suspended particulate matter (TSP) and particles with diameter less that 10 μm (PM_{10}) have been measured for tunnel-ventilated broiler facilities in Texas. Using TSP and particle size distribution samplers, a resulting emissions factor of 1.3 g PM_{10} $bird^{-1}$ of production (0.0029 lb PM_{10} $bird^{-1}$) was determined (Lacey et al. 2003). The authors compared these results to two European studies (Wathes et al., 1997; Takai et al, 1998) and found that their results were somewhat higher for TSP but the PM_{10} results were comparable with respirable particulate matter measured in the other studies. These authors speculate that the differences may be due to conditions and the sampling methodologies and technology employed. Because of the complexities of sampling particulate matter, the current study was unable to generate PM_{10} emission factors. Problems were encountered with obtaining sufficient sample for quantification using standard equipment. There are also potential problems with feathers coating equipment and collecting dust that need to be addressed.

Materials and Methods

The project approach was to perform emission tests at actively producing, mechanically-ventilated broiler houses with environmental climate controls. The majority of California broiler chickens are raised in these conditions, so the testing performed can be used to directly characterize emissions for the bulk of the industry. Also, using this type of facility simplifies the testing and analysis because of the precise control of airflow within the house. Testing can be performed under representative conditions with respect to the cycles of broiler production, animal density, animal age and size, waste handling, bedding material, litter treatments, design of poultry houses, and the diet and genetics of the animals. Testing can be performed during multiple stages of the broiler growth cycle in order to capture the emission potentials from a typical production cycle.

A typical mechanically ventilated poultry house is designed to provide optimal environmental conditions for the animal growth. Outside air is pulled through the house and expelled through a series of fans on the sides of the house to control the environment. During warm months when the broilers are 4 to 7 weeks old, air is pulled through a series of evaporative cooling pads at one end of the house and expelled through fans at the opposite end of the house (known as “tunnel” ventilation). When the broilers are young or the exterior temperatures are low, air is pulled through a series of controlled openings in the sidewalls near the roof of the house and the evaporative cooling pads are covered with curtains. During early brooding, heat must be added using heaters (propane is typical) to maintain house temperature with minimum ventilation rates to maintain sufficient moisture removal and indoor air quality. A control system monitors house temperature and regulates ventilation in response to age related, preset temperature requirements of the birds. Temperature, humidity, ventilation level, static pressure and heater status are recorded for each house.

The layout of the broiler house and ventilation system is given in Figure 1. It houses 21,000 broilers and has dimensions of 48 ft by 320 ft. The ventilations system consists of 10 fans: two 36" fans at 1/3 and 2/3 the length of the house, and a series of eight 48" fans at the end of the house opposite the evaporative cooler pads (fans are numbered as shown). The fans are constant speed with the 36" fans rated at 8,000 CFM and the 48" fans at 18,300 CFM. Ventilation rate is controlled by the number of fans operating or during early brooding by intermittent operation of one fan on a 5-minute cycle. The house is always ventilated and there are a total of 17 ventilation levels. The lowest level is operation of fan #10 for 10% of a cycle (~1,830 CFM) to the highest level with all fans operating 100% of the cycle (~146,400 CFM). After Day 28 of the growth cycle, at least some of the fans are in continuous operation all day during the spring, summer and fall, and in the afternoons in winter. Fan #10 is used in all of the ventilation modes.

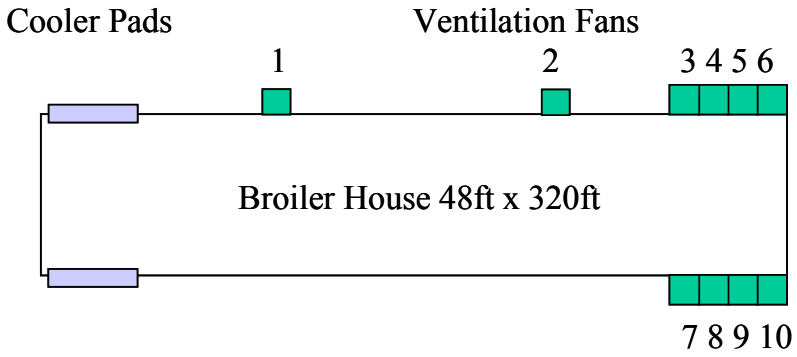

Figure 1. Components of ventilation system for mechanically-ventilated poultry house. Fans are numbered 1-10.

In order to measure airflow and concentration during a sampling cycle, a test "stack" or duct was added to the outlet of fan #10 to insure a stabilized airflow at the test equipment insertion point (Figure 2). The use of a duct is standard engineering protocol for most vent exhaust source testing methods. Airflow can be measured in the duct by performing a double transect across the diameter of the duct. A 48" diameter test duct was constructed with straightening vanes and test ports located 5 times the fan diameter from the fan with an additional 2 diameters to the opening. Pictures of the actual testing setup are given in Appendix B.

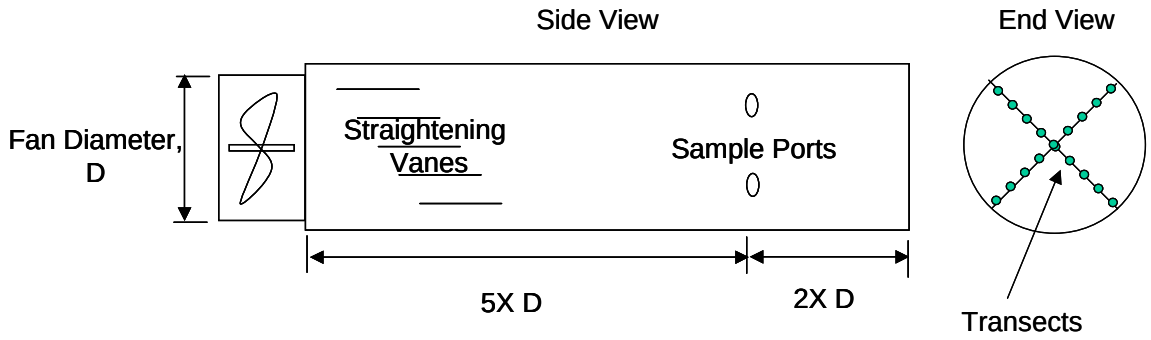

Figure 2. Schematic of test duct (not to scale) at fan outlet for insuring stabilized flow during concentration sampling. Transects of the stack are made to determine total stack airflow.

The typical daily ventilation cycle is important to consider for determining when air samples should be taken from the facility. If the ventilation levels are changing rapidly, it may be difficult to get an accurate measure of emissions because both the airflow and concentration will be changing rapidly. The ventilation system responds to outside heating load so spring, summer and fall ventilation levels increase rapidly during the morning hours from 8:00 to 12:00 and decrease rapidly from 19:00 to 23:00 in the evening. During testing the control system was set to a constant ventilation rate to control this characteristic. The house was allowed to equilibrate for several air exchanges before sampling.

Two sampling campaigns were performed, one during the late spring of 2004 and one during the fall of 2004. The first round of sampling focused on ammonia and screening level volatile organic gas evaluation using hydrocarbon methods. The second round of sampling focused on collecting more refined organic gas information. To minimize some of the environmental variables, both sample sets were performed at the same chicken house and testing was scheduled so the sampling was performed on second-run litter for both tests. The set point temperature for the house is controlled based on animal age and was similar over both tests, but ventilation rates were higher during the late spring tests due to high outdoor temperatures and the need for cooling ventilation. Propane heaters were operating to maintain house temperature during several of the sampling runs during the fall campaign. Important parameters for the broiler production house during the test sampling are given in Table 1.

Table 1. Summary of production conditions during both sampling campaigns.

House size	48’ x 320’
Number of birds	~21,000
Growth cycle	45 days, 10 days between flocks
Bedding material	rice hulls
Feed	5 formulated feeds depending on bird age
Temperature	adjusted with bird age
Minimum ventilation	adjusted with bird age
Litter	second run, full removal typical after 3rd flock
Litter conditioning	floor conditioning each cycle with bedding replacement at front 1/3 of house

A goal of the project was to account for temporal differences in emissions from broiler operations as the chickens grow in size, feed intake and excretions. In California, a typical growth cycle for broiler chickens takes 45 days from the time newborn chicks enter the house to harvest. Air samples were collected and emissions evaluated several days before chicks were introduced to the house to quantify emissions from second-run litter only (called day 0). Emissions measurements were repeated on approximately the 10^{th}, 20^{th}, 30^{th}, and 40^{th} day of bird age.

Analytical Methodology

In order to determine the emissions rate of gaseous compounds from the poultry house, two elements are needed, airflow and concentration enrichment. Since ambient air may also contain pollutants, concentration measurement may be needed in inlet (ambient) and outlet (stack). This allows determination of the pollutant enrichment generated by the interior environment of the house (Figure 3). Air is sampled and concentration is determined at the ambient (C_A) and stack (C_B) locations and the difference is taken to determine enrichment. In addition, two different fan operation scenarios may exist. In the first, only the stack fan is operating and all air flows through the stack (Figure 3a). During some test runs, other fans are running because additional ventilation was needed to maintain the environment for the birds in the house (Figure 3b). To account for this additional airflow, each fan must be calibrated in relationship to the test fan. With this calibration, a ventilation level factor (VLF) can be determined for each fan configuration. The VLF is multiplied by the flow measured in the stack fan ($Flow_B$) to determine the total house flow. House emissions are determined by the following formula:

$$Emissions = (C_B - C_A) \times (Flow_B \times VLF) \qquad (1)$$

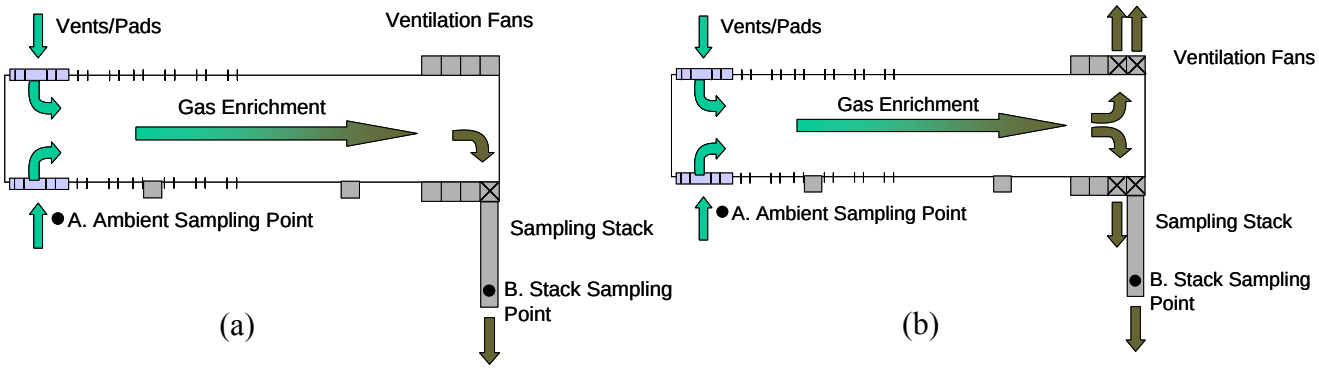

Figure 3. Schematic illustration of gas emissions enrichment from a mechanically ventilated broiler house measured with (a) only the stack fan operating, and (b) multiple fans operating.

The implicit assumption in this approach is that the concentration is the same at each fan. This assumption is reasonable because all fans are co-located at the opposite end of the house from the primary air inlets. A summary of the test methods used for flow and gas concentration is given in Table 2 and each is discussed below.

Table 2. Summary of source test methods used for flow and gaseous emissions measurement.

Measurement	***Method***	***Description***
Stack Airflow	CARB 2, CARB 4	12 point traverse of stack airspeed, temperature and humidity
Ammonia	BAAQMD Method	60 minute sample through impinger train of 0.1N HCl
Hydrocarbons	EPA Method 25A	60 minute continuous measurement with on-site FID
Hydrocarbons	EPA Method 18	Tedlar© bag collection, GC-FID for C1–C6+ compounds
Organic Gasses	EPA Method TO-15	Summa canister collection, GC-MS for 68 polar/non-polar target compounds with non-specific library search for other compounds reported relative to internal standard

Airflow Measurement

The airflow in the test stack was determined during each sampling run by using an "S" type pitot tube connected to an inclined manometer. A 12 point traverse through two ports provided average velocity and the air volumetric flow rate was determined using California Air Resources Board (CARB) Method 2. The stack temperature was determined by using a thermocouple and an indicating pyrometer. The proportion of water was determined using the wet-bulb/dry-bulb method and the dry molecular weight of the stack gas determined by CARB Method 4.

To account for this additional airflow, each fan was calibrated in relationship to the test fan with an empty house prior to the broiler cycle. The procedure used was to turn on all of the fans, set the static pressure at a high value (0.10), and measure the airflow by hand at 8 points on each fan. The procedure was repeated a low static pressure (0.05). Both a vane type and hot wire anemometer were used and gave consistent relative results. This is an abbreviated manual version of a procedure developed for quantifying absolute airflow for poultry fans (Gates et al., 2002). Since we are only interested in relative airflow we reduced the number of grid points. The relative airflow did not appear to be impacted by static pressure and the other 48 inch fans were 5-10% greater airflow than the stack fan (presumably because of the additional resistance of the stack). For the 36 inch fans the relative flow was adjusted for both the flow and the area difference of the fan.

Ammonia

Ammonia concentrations were determined according to Bay Area Air Quality Management District (BAAQMD) Method ST-1B. The exhaust gases were extracted through an impinger train containing 0.1N HCl. For each sampling run, two samples were collected at a constant rate of 0.75 cfm for approximately sixty (60) minutes. The samples were recovered in the field, placed on ice, and returned to the laboratory for analysis. The samples were sent to Calscience Environmental Laboratories for analysis. The results are reported from the laboratory as mg NH_3 $sample^{-1}$ and converted into ppmv using the flow and sample collection period.

Organic Gasses – Hydrocarbon Methods

Two screening level hydrocarbon analyses were performed during the spring 2004 sampling campaign. Continuous total hydrocarbon (THC) monitoring was performed in the stack and in the ambient air near the air intake vents at the front of the house in accordance with EPA Method 25A. The THC samples at the outlet and in the ambient air were extracted and delivered to the analyzers through a heated Teflon line. All sampling components were stainless steel or Teflon. Calibrations were performed before and after each test-run with zero gas and propane span gas. The outlet and ambient air THC concentrations were measured utilizing a California Instruments Model 300H FID (flame ionization detection) hydrocarbon analyzer. All THC data was continuously recorded on a Linseis chart recorder. Instrument data was recorded every one (1) minute, using a data-logger, and corrected for analyzer calibration drifts with spreadsheets. The method detection limit for the THC testing is 0.5 ppmv as propane.

Calibrations for the THC tests were performed with propane calibration standards. All pre and post span calibrations were performed with EPA protocol 1 gases, directly from the bottles. Initial multipoint calibrations were performed on the FID with three (3) levels of span gas and a zero gas to demonstrate linearity throughout the measurement range. Initial calibrations and the multipoint calibrations were performed at the analyzer sample inlet. Subsequent calibrations were performed through the probe tip of the sample system, (Bias calibrations). Bias calibrations were performed before and after each test-run. The initial bias checks agreed with the pretest instrument calibrations to within 3%.

Hydrocarbons were also quantified using EPA Method 18. During the sampling run, a Tedlar bag exhaust sample was collected from the outlet of the exhaust stack. An ambient sample was also collected. The bags were stored in a dark container and transported to the laboratory for low level hydrocarbon analysis (C1–C6+ compounds) by gas chromatography utilizing a flame ionization detection system. AIRx Testing, in Ventura, California, performed the analysis. Reactive hydrocarbon concentrations are estimated by taking the sum of all detected hydrocarbons and subtracting the estimated methane (C1) and ethane (C2) contents. The minimum quantification limit for this method is 0.3 ppmv for each hydrocarbon class.

Organic Gasses – Gas Specific GCMS Method

During both the spring and fall sampling campaigns, samples were taken and analyzed for specific gas composition using EPA Method TO-15, a gas chromatograph/mass spectrometer (GCMS) method. This method was chosen because it offered low levels of detection (ppbv range) for 69 specific target compounds and the opportunity to tentatively identify and estimate other organic compounds in the samples. This method is also commonly specified for indoor air quality testing where the gas profile is unknown. The sampling train is specified to allow detection of both polar and non-polar compounds. The target species list includes alcohols and ketones that may be expected from a biological source.

Samples were collected using sanitized, evacuated summa canisters and submitted to Atmospheric Analysis & Consulting for analysis by EPA Method TO-15. The results are reported in units of ppbv. The laboratory also performed a non-target compound library search to tentatively identify other compounds present in the canister sample. The confidence level in the identification was computed along with the total area of the peak. This area was compared with the internal calibration to estimate the concentration of the tentatively identified compound in ppbv.

Quality Assurance/ Quality Control

All samples were taken following the aforementioned standard procedures by a licensed emissions testing firm (AirX Testing) that operates within the San Joaquin Valley Unified Air Pollution Control District. Standard sample handling and record keeping practices were maintained for all samples collected during the two sampling campaigns. Fan operations data was recorded by the house control system and verified in the field at the time of sampling. Complete reports including all measurements, calibrations and laboratory analysis were generated by AirX Testing and a list of these reports is contained in Appendix C. As an additional assurance, the California Air Resources Board, Monitoring and Laboratory Division performed a review of the field collection and laboratory practices used during the second sampling run for volatile organic gasses. This review is included in Appendix D.

Results and Discussion

The measured concentrations of ammonia in the test stack during the testing are shown in Table 3. Ammonia results showed an increase in ammonia emissions with broiler age ranging from 0.48×10^{-4} lb day^{-1} bird^{-1} (0.02 g day^{-1} bird^{-1}) on day 17 to 10.9×10^{-4} lb day^{-1} bird^{-1} (0.49 g day^{-1} bird^{-1}) on day 43. This is in a reasonably consistent but somewhat lower than the range reported in other recent studies on broiler emissions of ammonia in the United States mentioned above (Casey et. al., 2003; Lacey et. al., 2003).

Table 3. Concentration and flow data for ammonia during spring sampling campaign.

Bird Age (days)	Date	Time	Ammonia Conc. (ppmv)	House Flow (dscfm)	House Emissions (lb/hr)
0 (litter)	4/26	11:28	5.9	15,743	0.25
0 (litter)	4/26	12:00	6.3	15,907	0.27
0 (litter)	4/26	13:37	6.5	16,070	0.28
18	5/17	10:23	0.8	18,098	0.04
18	5/17	13:03	0.7	29,071	0.06
28	5/27	6:15	2.2	27,464	0.16
28	5/27	8:32	1.6	43,739	0.19
28	5/27	11:05	0.8	65,394	0.14
28	5/27	13:00	0.4	104,591	0.12
42	6/11	6:00	3.4	67,394	0.61
42	6/11	11:08	2.5	131,269	0.90
42	6/11	13:10	2.4	128,910	0.82

The amount of ammonia emission appears to correlate to the size and amount of excretion of the broilers as discussed above. An exponential expression is used to fit this growth related phenomenon. Figure 4 shows the emissions rate per animal relative to age along with the equations for the best fit. Integrating under the exponential curve gives a cycle emission of 0.0112 lb bird^{-1} (5.1 g bird^{-1}) during the growth cycle. Ammonia emissions from the litter continue after the birds are removed until the litter is either dried during house heating for the next broiler cycle or when the litter is cleaned and removed from the house. Using the day 0 data, the estimated daily emissions for the second run litter tested before the birds were placed was 3.13x10^{-4} lb day^{-1} bird^{-1} (0.14 g day^{-1} bird^{-1}) giving an estimated 55 day production cycle ammonia emissions of 0.0143 lb bird^{-1} (6.5 g bird^{-1}). This is lower than the 31 g bird^{-1} reported by Lacey et al. (2003) for broiler houses in Texas, but these authors found that their results were higher than several European studies of poultry emissions. Differences may be attributable to cycle length, litter management, feed, climate and other process factors along with differences in methodology. As noted by the National Research Council (NRC, 2003), further work is needed to determine how these process factors affect emissions.

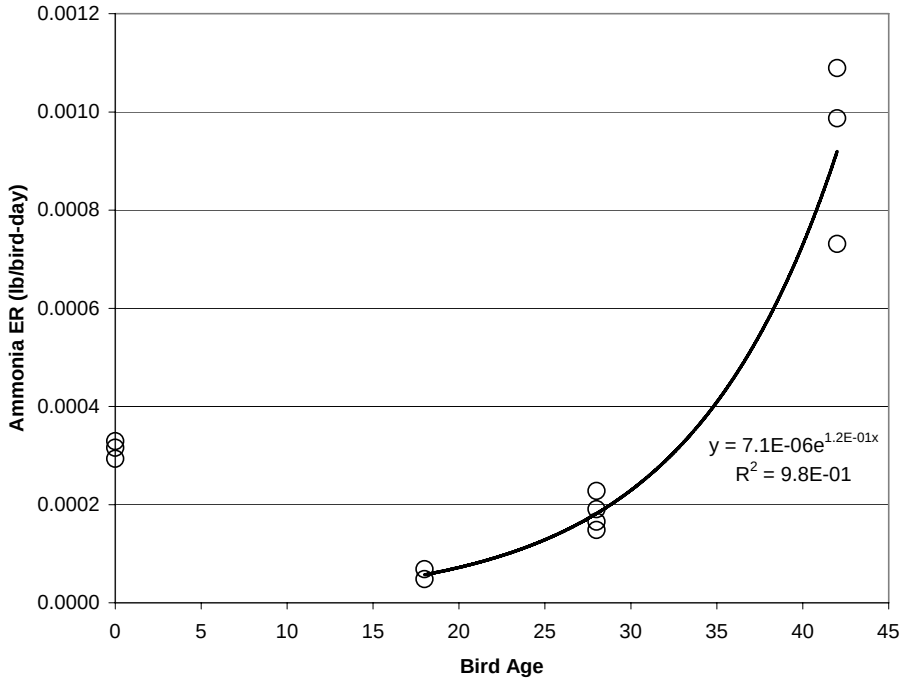

Figure 4. Ammonia emissions rate as a function of bird age for with exponential curve fit. Note that day 0 data represents emissions between cycles before litter is dried during initial house heating, not included in fit.

The results of the hydrocarbon analyses from the spring sampling run are shown in Table 4. All concentrations measured were near the minimum quantification limit of the method. For EPA Method 25A, the stack results were typically somewhat larger than the ambient for most sampling runs. For EPA Method 25A, the C1 (methane) response was

detected for all samples but was often greater in the ambient air than in the stack air. One conclusion would be that methane emissions do not appear to be significant for poultry production. A C4 response was present in both the stack and ambient on the day 0 (litter only) sampling run and a C2 response in both on the day 18 sampling run. For all other compounds and runs the response was non-detect above the minimum quantification limit for the method of 0.3 ppmv.

Table 4. Concentration and flow data for hydrocarbons during spring sampling campaign.

				Method>	EPA25A	EPA18*		
					THC	C1	C2	C4
				CalGas>	Propane	Methane	Ethane	Butane
BirdAge (days)	Date	Time	House Flow (dscfm)	MQL>	0.5 (ppmv)	0.3 (ppmv)	0.3 (ppmv)	0.3 (ppmv)
0 (litter)	4/26	12:15	15,743	Stack	*NS*	2.4		0.6
				Ambient	*NS*	3.6		2.0
0 (litter)	4/26	14:15	16,070	Stack	2.0	2.2		2.3
				Ambient	2.0	4.1		1.9
18	5/17	12:00	18,098	Stack	4.6	2.1	1.0	
				Ambient	2.0	2.1	0.4	
18	5/17	13:30	29,071	Stack	4.8	1.6	0.4	
				Ambient	1.2	2.0	0.6	
28	5/27	6:40	27,464	Stack	1.7	2.3		
				Ambient	1.3	1.7		
28	5/27	8:32	43,739	Stack	1.7	2.0		
				Ambient	1.3	2.9		
43	6/11	10:00	67,394	Stack	1.4	2.8		
				Ambient	1.1	4.3		
43	6/11	14:00	128,910	Stack	0.6	2.5		
				Ambient	1.3	3.0		

*Non-detect is indicated by blank space. C3, C5, C6, C6+ compounds were not detected (MQL = 0.3 ppmv) for all sampling runs and are not shown.
MQL = Minimum quantification limit
NS = Not sampled during this run

An estimate of total organic gas emissions was made based on this screening analysis by subtracting the ambient concentration from the stack concentration and using the house flow and mass properties of the calibration gas to estimate emissions. Figure 5 shows the results for house emissions. The trend between the EPA Method 25A and EPA Method 18 appears to correspond somewhat, but Method 18 shows negative emissions because of greater response in the ambient air than the stack air. This phenomenon is difficult to explain, but the low level of detection indicates that these hydrocarbon methods may have limited suitability for this type of testing. It appears that these methods may not be sensitive enough to detect the compounds or low concentrations present in the poultry air.

Additionally, these methods assume that the response of the flame ionization detector to the compound mix is comparable to a standard hydrocarbon compound like methane or propane. This may not be the case for the compounds in the poultry air. This makes the results only semi-quantitative and may not provide useful information on total mass

emissions. Because of these shortcomings, efforts after the spring sampling run concentrated on the more sensitive and specific EPA Method TO-15.

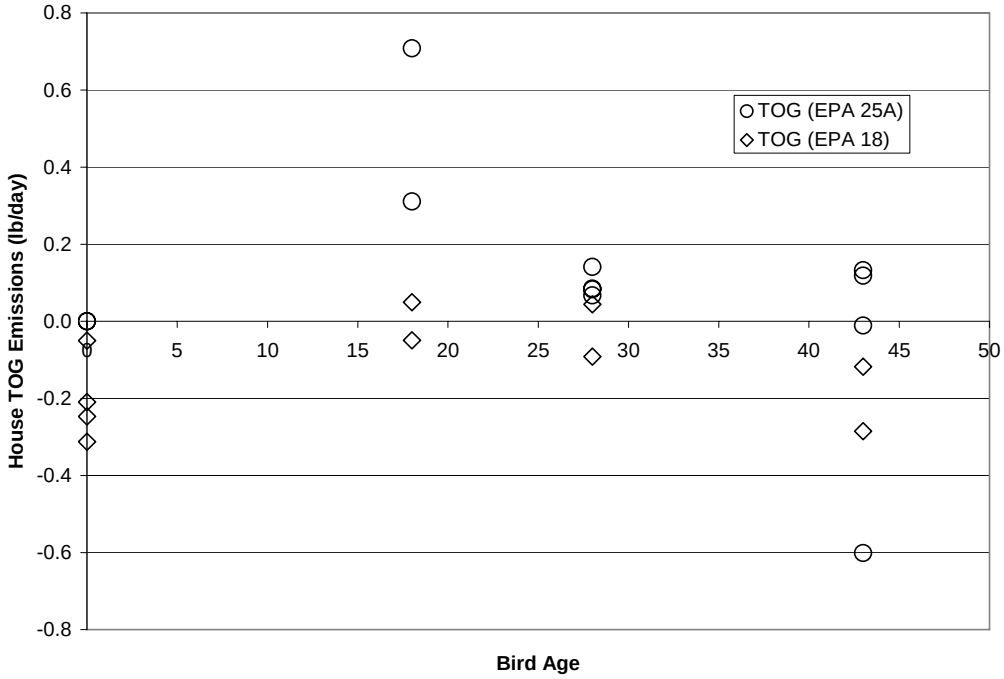

Figure 5. Broiler house total organic gas emissions as estimated by EPA Method 25A and EPA Method 18 reported as lb/day. Results may not be quantitative.

The EPA Method TO-15 utilizing GCMS has much higher sensitivity and can identify specific compounds in the air mixture, alleviating some of the problems with the hydrocarbon methods. Only a limited number of TO-15 samples were collected during the spring run and ambient samples were not always taken to correct for compounds in the outside air. An additional run in the same house under the same litter conditions was performed in the fall to collect additional organic gas data. Results are shown in Table 5 including the ambient and stack concentrations of the target compounds and the tentatively identified compounds that were positively detected during the sampling campaigns. Only the detected target compounds are shown on Table 5. A complete list of the target compounds and detection limits from the calibration standard are shown in Appendix A. It should be noted that the identification and quantification of the tentatively identified compounds is approximate because the GCMS response is compared to an internal standard and not a calibration standard for the specific gas.

Table 5. Organic gas concentrations from broiler house quantified using EPA Method TO-15 (concentrations in ppbv).

			Stack									Ambient					
		Date>	5/17	5/27	6/11AM	6/11PM	10/15	10/29	11/9	11/18	11/29	6/11	10/15	10/29	11/9	11/18	11/29
		Bird Age (days)>	18	28	43	43	0	9	20	29	40	43	0	9	20	29	40
		Flowrate (dscfm)>	18,098	27,299	67,392	128,910	14,305	16,031	15,294	26,451	28,222	67,392	14,305	16,031	15,294	26,451	28,222
Chemical Compound	**Molecular Wt.**	**MDL**															
Methanol	32.04	20.0	379	171	91	78			301	393			77				
Propylene	42.06	0.5					17				3.1		4.3				4.2
Ethanol	46.07	2.5	114		27	17		46	114	43	10		59	9.4		3.8	8.2
Acetone*	58.08	1.0	50	1194	26		13	1313	69	50	6.5		13	22	19		5.0
Isopropyl Alcohol	60.1	1.0					2.6										
Carbon Disulifde	76.2	0.5		2.9						6.5							
Benzene	78.1	0.5					1.6						7.8				1
Cyclohexane	84.2	0.5											3.4				
Methylene Chloride*	84.9	1.0		11			1.4	12	6		0.9		1.4	5.6		2.6	1.4
Vinyl Acetate	86.06	0.5	173	27		5	1.2	14	62	35	5.3		1.8			1.6	1.3
Hexane	86.14	0.5	5.2	4.1			1.5	16	6.3	3.8	0.7		2				1
Chlorodifluoromethane*	86.48	1.0											1				
Toluene	92.08	0.5	2.5	2.1			3.2	4.6					6.2				3.7
Heptane	100.2	0.5											1.4				
m- & p-Xylenes	106.2	0.5											1.5				1.4
4-Methyl-2-Pentanone (MiBK)	116.2	0.5					1.3										
Dichlorodifluoromethane*	120.93	0.5	2.3	2.2	2	4						3.3	1.1				
Ethylene Oxide	44	TIC				11											
Acetaldehyde	44.05	TIC	99		9.9				24				23		13	9.3	6.5
Propane	44.1	TIC	24	53					919	340					855	31	
2-methyl-1-propene	56.08	TIC															3.4
Isocvanomethane	57.05	TIC		83													
Propanal	58.06	TIC	11														
Isobutane	58.12	TIC	11		13	14	17		277		4.4	4397			280		
Butane	58.12	TIC					26		42		4.7	87			44		4
Methyl Formate	60.1	TIC	7.6														
Dimethyl Sulfide	62.13	TIC	7.5														
nitromethane	64.06	TIC													8.9	4.5	
2-Butanone	72.1	TIC							6.2		0.7						
Pentante (Pentane)	72.12	TIC											13				
2,2-dimethyl-Propane	72.12	TIC														29	
2-methylbutane	72.2	TIC			4		28		26		4.3		37		24		3.9
Methyl acetic Acid	74.1	TIC	5.6														
Thiourea	76.1	TIC														3.6	
1-hexene	84.16	TIC										54					
Methylcyclopentane	84.2	TIC											17				
2-methylpentane	86.18	TIC	5.1														
3-methylpentane	86.2	TIC											7.5				
2,2-dimethylbutane	86.2	TIC							10								
Dimethyl disulfide	94.2	TIC	22		46	19				237	16						
3-Furanmethanol	98.1	TIC								51							
Methylcyclohexane	98.19	TIC											12				
2-Methylhexane	100.2	TIC											3.1				
3-Methylhexane	100.2	TIC											3.9				
Heptanal	114.2	TIC				5.9											
2,2,3,3,tetramethylbutane	114.26	TIC															5.1
A-pinene	136.16	TIC											3.1				
Trichloromonofluoromethane*	137.7	TIC											8.3				
diethoxy hexamethylsiloxane	162	TIC				3.1											
Hydrogen sulfate 0-methylisourea	172.15	TIC	8.9														
Hexamethyl Cyclotrisiloxane*	222.54	TIC				28										19	

*Compound is exempt, (not Reactive Organic Gas). TIC = Tenatively Identified Compound. MDL = Method Detection Limit, blank space indicates compound at less than MDL.
EPA TO-15 target compounds with no detections were omitted from table. See Appendix A for complete target list.

Total organic gas was calculated as the sum of all of the identified target compounds and the tentatively identified compounds for each sampling run. Figure 6 shows the total organic gas emitted from the house from the spring and winter runs without correction for ambient concentrations. The corrected fall data is given in Figure 7 subtracting ambient from house concentration. To compute the emissions factor per bird produced the average emissions rate for the five sampling runs was multiplied by the number of days of production (55 total including 45 days with growing birds in the house and 10 days between cycles) and divided by the number of birds produced. An average total organic gas (TOG) emissions rate of 0.095 lb hr^{-1} for the house is obtained and a production cycle emissions of 0.0061 lb $bird^{-1}$ (2.83 g $bird^{-1}$) is estimated.

The types of gasses detected were fairly consistent and were dominated by a few compounds. The average emissions rate for organic gasses that showed positive emissions over the cycle are shown in Table 6. Total organic gas and the reactive organic gas are also computed from each sampling run and the average from the 5 sampling runs is reported in Table 6. The mass composition of the organic gas generated in the house is also determined. Note that the quantification and identification of the compounds in italics are tentative because they were detected by GCMS but not part of the available TO-15 target standard.

Some of the compounds detected as part of TOG are excluded compounds in terms of ozone formation and regulation. Because the TOG species are identified we can readily determine from the speciation profile the reactive portion or the reactive organic gasses (ROG) as named by the California Air Resources Board. Here the average house ROG emission for the fall is 0.057 lb hr^{-1} with estimated production cycle emissions of 0.0037 lb $bird^{-1}$ (1.70 g $bird^{-1}$).

The key compounds in terms of mass emissions that were part of the TO-15 standard were acetone, methanol, vinyl acetate, and ethanol. Dimethyl disulfide, and propane were tentatively identified during multiple sampling runs by GCMS analysis. The compound 3-Furanmethanol was tentatively identified in a large quantity on only one sampling event and may not be a reliable result. Figure 8 shows the house emissions rates for some of the consistently detected compounds over both sampling campaigns.

The source of the compounds detected in the house was not investigated but may not exclusively be from birds or manure. Many of the organic compounds detected have been noted in other studies that focused on odors from birds and manure (Chang and Chen, 2003; Hobbs et al., 1995). Propane heaters, feed and supplements, and off gassing from house materials and equipment are other potential sources of emissions. Propane and vinyl acetate, not noted in the odor studies, may come from these other sources.

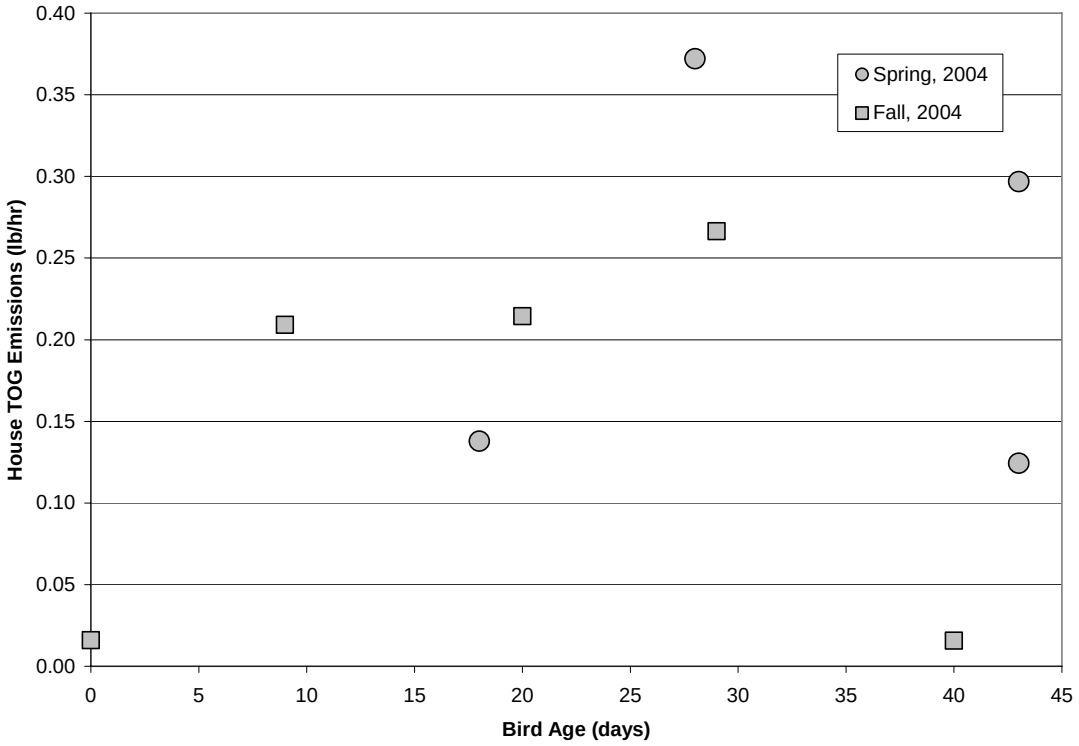

Figure 6. House total organic gas emissions as estimated from EPA Method TO-15 for spring and fall sample runs (not corrected for ambient concentrations).

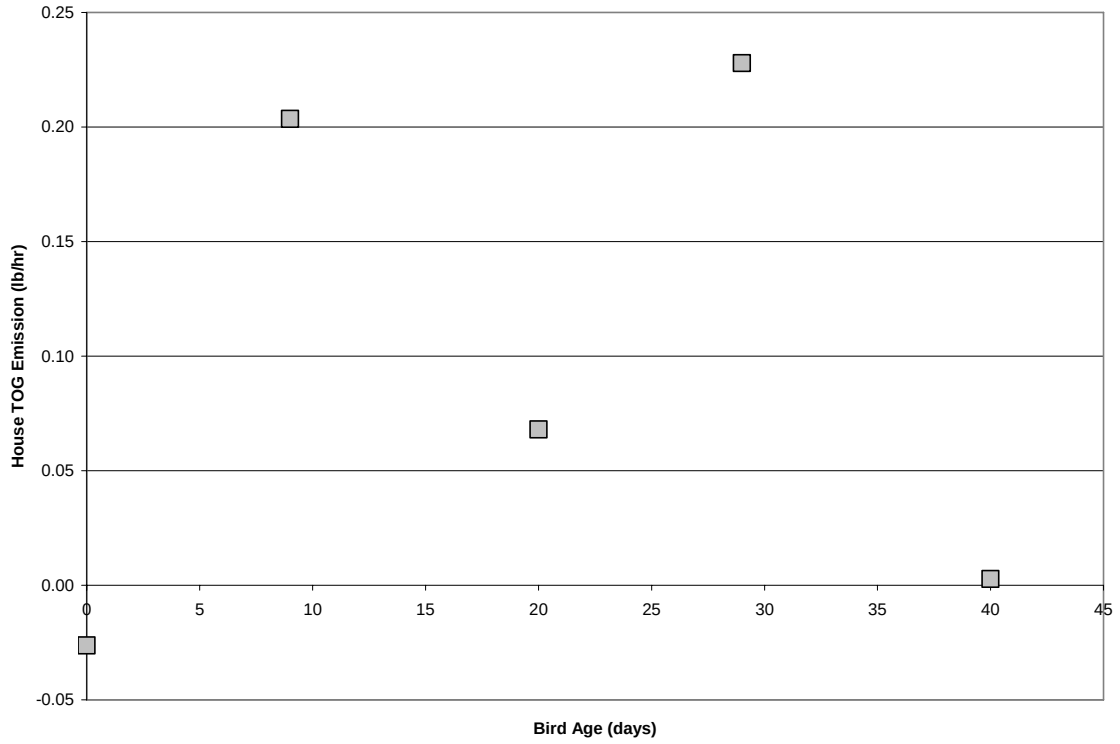

Figure 7. Ambient corrected house organic gas emissions as estimated by EPA Method TO-15 for fall sample run.

Table 6. Average organic gas emissions rate per unit of production during a 55-day broiler cycle (Fall 2004). As detected by EPA Method TO-15 with tentatively identified and quantified compounds in italics.

Organic Compound	**Average (g/bird)**	**St. Dev. (g/bird)**	**Speciation (% mass)**
Acetone*	1.246	2.467	39.3
Methanol	0.419	0.722	13.2
Vinyl Acetate	0.175	0.182	5.5
Ethanol	0.111	0.212	3.5
Hexane	0.035	0.044	1.1
Carbon Disulifde	0.012	0.028	0.4
Methylene Chloride*	0.009	0.029	0.3
Propylene	0.006	0.017	0.2
Isopropyl Alcohol	0.002	0.005	0.1
4-Methyl-2-Pentanone (MiBK)	0.002	0.005	0.1
Dimethyl disulfide	*0.595*	*1.222*	*18.7*
Propane	*0.379*	*0.740*	*12.0*
3-Furanmethanol	*0.124*	*0.278*	*3.9*
Butane	*0.020*	*0.046*	*0.6*
Isobutane	*0.018*	*0.032*	*0.6*
2,2-dimethylbutane	*0.012*	*0.028*	*0.4*
2-Butanone	*0.008*	*0.014*	*0.2*
Total Organic Gas	**2.83**	**3.43**	
Reactive Organic Gas	**1.70**	**3.08**	

Averages of five measurements taken over a 55-day broiler cycle in Fall 2004.
Compounds with negative enrichment are not shown or included in speciation.
* signifies exempt compounds (not ROG)

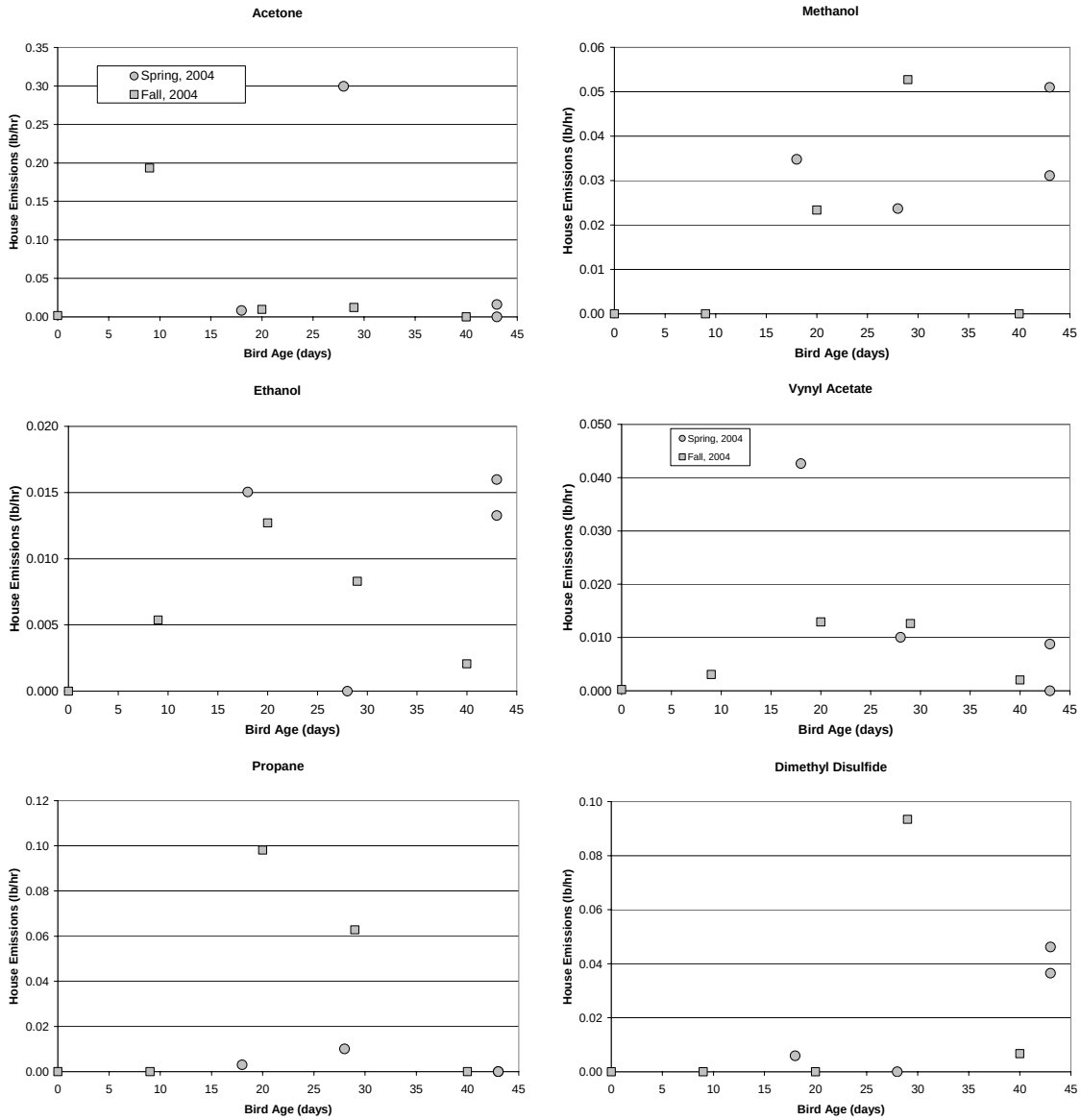

Figure 8. Broiler house emissions of key organic gasses detected by GCMS (EPA TO-15) as a function of bird age for spring and fall campaigns. Note that emissions rates are not corrected for ambient concentrations.

Conclusion

This study was able to generate ammonia and organic gas emissions estimates for a typical broiler production cycle, expressed on a per bird of production basis. The study did not look at the effects of location, seasonal variability or other parameters on cycle emissions. However, annual emissions factors are needed in order to calculate the facility emissions of California broiler facilities given their capacity. Annualized emissions factors for broiler production in California can be estimated from the cycle emissions developed in this study. To achieve this, the emissions measured during the spring and fall campaigns of this study are assumed to represent the entire year. Cycle time was a total of 55 days (45 days of broiler growth and 10 days between broods) so the house has the potential of raising 6.7 broods per year. The annual emissions factor is therefore 6.7 times the per bird estimates. A summary of emissions factors for broiler production developed in this study is given in Table 7 including the production and annual capacity estimates.

Table 7. Gas emissions factors for broiler production as estimated by this study.

Compound	Production Emission Factor (lb $bird^{-1}$)	Capacity Emission Factor (lb $bird^{-1}$ yr^{-1})
Ammonia	0.0143	0.096
Total Organic Gas*	0.0061	0.041
Reactive Organic Gas	0.0037	0.025

*Gas speciation profile is given in Table 6 and includes tentatively identified compounds.

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References

Casey, K.D., R.S. Gates, E.F. Wheeler, J.S. Zajaczkowski, P.A. Topper, H. Xin, Y. Liang. 2003. Ammonia emissions from broiler houses in Kentucky during winter. *International Symposium on Gaseous and Odour Emissions from Animal Production Facilities*. Horsens, Jutland, Denmark. June 1-4, 2003.

Chang, M.H. and T.C. Chen. 2003. Reduction of Broiler House Malodor by Direct Feeding of a Lactobacill Containing Probiotic. *International Journal of Poultry Science* 2(5): 313-317.

Demmers, T. G. M., L. R. Burgess, J. L. Short, V. R. Phillips, J. A. Clark, and C. M. Wathes. 1999. Ammonia emissions from two mechanically ventilated U.K. livestock buildings. *Atmospheric Environment* 33(2): 217–227.

Gates, R.S., J. D. Simmons, K. D. Casey, T. J. Greis, H. Xin, E. F. Wheeler, C. L. King and J. R. Barnett. 2002. Fan Assessment Numeration System (FANS) design and calibration specifications *ASAE Meeting Paper* No. 024124. St. Joseph, Mich.: ASAE.

Groot Koerkamp, P. W. G., J. H. M. Metz, G. H. Uenk, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, J. Hartung, J. Seedorf, M. Schroder, K. H. Linkert, S. Pederson, H. Takai, J. O. Johnsen, and C. M. Wathes. 1998. Concentrations and emissions of ammonia in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research* 70(1): 79–95.

Grubb, W., C. A. Rollo, and J. R. Howes. 1965. Dust problems in poultry environments. *Transactions of the ASAE* 8(5): 338–339.

Hobbs, P., B.F. Pain and T.H. Misselbrook. 1995. Odorous compounds and their emission rates from livestock waste. *Proceedings International Livestock Odor Conference*. Iowa State University. Ames, IA. pp.11-15.

Hyde, B. P., O. T. Carton, P. O'Toole, and T. H. Misselbrook. 2003. A new inventory of ammonia emissions from Irish agriculture. *Atmospheric Environment* 37(1): 55–62.

Lacey, R.E., J. S. Redwine, C. B. Parnell, Jr. Particulate matter and ammonia emissions factors for tunnel-ventilated broiler production houses in the southern U.S. *Transactions of the ASAE* 46(4): 1203–1214.

National Research Council. 2003. *Air Emissions from Animal Feeding Operations:Current Knowledge, Future Needs.* Report from Ad Hoc Committee on Air Emissions from Animal Feeding Operations, Committee on Animal Nutrition, National Research Council. National Academies Press, Washington, D.C. 286 pages.

O'Neill, D. H. and V.R. Phillips. 1992. A review of the control of odour nuisance from livestock buildings: Part 3, Properties of the odorous substances which have been identified in livestock wastes or in the air around them. *Journal of Agricultural Engineering Research*. 53:23-50.

Takai, H., S. Pederson, J. O. Johnsen, J. H. M. Metz, P. Koerkamp, G. H. Uenk, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, J. Hartung, J. Seedorf, M. Schroder, K. H. Linkert, and C. M. Wathes. 1998. Concentrations and emissions of airborne dust in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research* 70(1): 59–77.

Yasuhara, A., 1987. Identification of volatile compounds in poultry manure by gas chromatography-mass spectrometry. *Journal of Chromatography* 387: 371-378.

Wathes, C. M., M. R. Holden, R. W. Sneath, R. P. White, and V. R. Phillips. 1997. Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in U.K. broiler and layer houses. *British Poultry Science* 38(1): 14–28.

Appendices

Appendix A. Target compounds for EPA Method TO-15 Analysis

Chemical Compound	***Method Detection Limit***
Chlorodifluoromethane	1.0
Propylene	0.5
Dichlorodifluoromethane	0.5
Chloromethane	0.5
1,2-Dichloro-1,1,2,2-Tetrafluoroethane	0.5
Vinyl Cloride	0.5
Methanol	20.0
1,3-Butadiene	0.5
Bromomethane	0.5
Chloroethane	0.5
Dichlorofluoromethane	0.5
Ethanol	2.5
Vinyl Bromide	0.5
Acetone	1.0
Trichlorofluoromethane	0.5
Isopropyl Alcohol	1.0
Acrylonitrile	0.5
1,1-Dichloroethylene	0.5
Methylene Chloride	1.0
Allyl Chloride (Chloroprene)	0.5
Carbon Disulifde	0.5
1,1,2-Trichloro-1,2,2-Trifluoroethane	0.5
t-1,2-Dichloroethylene	0.5
1,1-Dichloroethane	0.5
MTBE	0.5
Vinyl Acetate	0.5
2-Butanone (MEK)	1.0
cis-1,2-Dichloroethene	0.5
Hexane	0.5
Chloroform	0.5
Ethyl Acetate	0.5
Tetrahydrofuran	0.5
1,2-Dichloroethane	1.0
1,1,1-Trichloroethane	0.5
Benzene	0.5
Carbon Tetracloride	0.5
Cyclohexane	0.5
1,2-Dichloropropane	0.5
Bromodichloromethane	0.5
1,4-Dioxane	1.0
Trichloroethene	1.0
2,2,4-Trimethylpentane	0.5
Heptane	0.5
cis-1,3-Dichloropropene	0.5
4-Methyl-2-Pentanone (MiBK)	0.5
t-1,3-Dichloropropene	0.5
1,1,2-Trichloroethane	0.5
Toluene	0.5
2-Hexanone	1.0
Dibromochloromethane	0.5
1,2-Dibromoethane	0.5
Tetrachloroethylene	0.5
Chlorobenzene	0.5
Ethylbenzene	0.5
m- & p-Xylenes	0.5
Bromoform	0.5
Styrene	0.5
1,1,2,2-Tetrachloroethane	0.5
o-Xylene	0.5
4-Ethyltoluene	0.5
1,3,5-Trimethylbenzene	0.5
1,2,4-Trimethylbenzene	0.5
Benzyl Cloride	1.0
1,3-Dichlorobenzene	0.5
1,4-Dichlorobenzene	0.5
1,2-Dichlorobenzene	0.5
1,2,4-Trichlorobenzene	1.0
Hexachlorobutadiene	1.0

Appendix B. Photos of field testing setup

Figure A1. Broiler production house showing sampling stack attached to Fan#10 at back of house and ambient sampling at evaporative cooler/vent inlets at front of house.

Figure A2. Sampling stack shown during airflow measurement and sampling.

Figure A3. Calibration of fans in interior of house to determine ventilation level factor.

Figure A4. Interior of poultry house prior to introduction of broilers showing bedding, animal feeders, and open vents along roofline.

Appendix C. Source test reports

Complete list of data and quality assurance reports referenced by this study. Reports were prepared by:

AIRx Testing
P.O. Box 1077
17331 Sharon Blvd.
Madera, CA 93639

- Engineering Testing of Chicken House Stack
  Tested On: April 26, 2004
- Engineering Testing of Chicken House Stack
  Tested On: May 17, 2004
- Engineering Testing of Chicken House Stack
  Tested On: May 27, 2004
- Engineering Testing of Chicken House Stack
  Tested On: June 11, 2004
- Engineering Testing of Chicken House Stack
  Tested On: October 15, 2004
- Engineering Testing of Chicken House Stack
  Tested On: October 29, 2004
- Engineering Testing of Chicken House Stack
  Tested On: November 9, 2004
- Engineering Testing of Chicken House Stack
  Tested On: November 18, 2004
- Engineering Testing of Chicken House Stack
  Tested On: November 29, 2004

Appendix D. VOC sampling and analysis audit

Attachment.